Claims

What is claimed is:

1. A method for determining a property of a portion of a substrate, the method comprising:

generating a first beam of electromagnetic radiation modulated at a predetermined frequency;

focusing the first beam on a region on said substrate, the energy of photons in said first beam that are not reflected by said region being converted into heat, said predetermined frequency being sufficiently small to cause a majority of said heat to transfer by diffusion from said region;

measuring the power of a portion of a second beam of electromagnetic radiation, wherein the portion is reflected by said region, and is modulated in phase with modulation of said first beam.

2. The method of Claim 1 wherein:

said predetermined frequency is smaller than a maximum frequency, said maximum frequency being inversely related to at least one of:

length of a conductive line that includes said region in said substrate; and

a distance at which the temperature of said conductive line is an order of magnitude smaller than the temperature in said region.

3. The method of Claim 2 wherein:

said conductive line has a length of approximately 100 microns; and

said maximum frequency is approximately 1000 Hz.

4. The method of Claim 2 further comprising:

forming said conductive line in an integrated circuit die by using at least one process parameter; and

changing said process parameter depending on said power of said second beam.

5. The method of Claim 2 wherein the predetermined frequency is less than:

$$\frac{\pi \kappa_m}{25L^2}$$

wherein:

κ_m is thermal diffusivity of the metal; and

L is length of said conductive line.

6. The method of Claim 2 further comprising, after the generating, focusing and measuring:

changing the power of said first beam; and

measuring a change in power of said reflected portion of said second beam in response to said changing.

7. The method of Claim 6 further comprising:

computing, in a programmed computer, a ratio of the difference in power of said portion of said second beam to a corresponding difference in power of said first beam; and

using said programmed computer to compute the resistance per unit length of said conductive line by dividing said ratio by a predetermined constant.

8. The method of Claim 7 wherein said constant is determined from the formula:

$$\sqrt{4\pi\varepsilon_0 \frac{c}{\lambda}\left(\frac{q}{\pi k_B}\right)}\left(\frac{(1-R)}{4}\right)\sqrt{\frac{3h_m h_i}{K_i T_0}\left(\frac{.92}{T_\theta}\right)}$$

wherein:

c is speed of light in vacuum

T is thickness of said conductive line;

λ is wavelength of said first beam;

ε_0 is the dielectric constant of free space;

q is the electron charge;

k_B is the Boltzmann's constant;

R is absolute reflectance of said conductive line;

h_m is the thickness of the region;

h_i is the thickness of an insulating material underneath the region;

K_i is the thermal conductivity of the insulating material;

T_0 is the ambient temperature; and

T_θ is the Debye temperature.

9. The method of Claim 1 wherein:

said measuring includes using a lock-in amplifier tuned to said predetermined frequency.

10. The method of Claim 9 wherein said measuring further includes:

using a silicon wafer to filter out at least a portion of said first beam reflected by said conductive line.

11. The method of Claim 10 wherein said measuring also includes:

using a narrow band filter tuned to the wavelength of said second beam to filter out at

least another portion of said first beam reflected by said conductive line.

12. The method of Claim 1 further comprising:
comparing the power measured in said region with a predetermined limit.

13. The method of Claim 1 further comprising:
focusing the first beam on a second region adjacent to said region; and
repeating said measuring.

14. The method of Claim 13 further comprising:
changing a process parameter used in fabricating said wafer if the power measured in said region is greater than the power measured in said second region by a predetermined limit.

15. The method of Claim 13 further comprising:
focusing the first beam on a third region, wherein said region, said second region and said third region define a triangular area on said conductive line; and
repeating said measuring.

16. The method of Claim 15 further comprising:
changing the power of said first beam; and
repeating said measuring.

17. The method of Claim 1, wherein during said generating, said first beam has a first power incident on said region at least ten times greater than a second power of said second beam incident on said region.

18. The method of Claim 1 wherein said power has a modulated component, the method further comprising:

dividing a parameter, related to the amplitude of said modulated component by the value of said constant component to obtain a measure of the change in reflectance normalized by the absolute reflectance.

19. The method of Claim 1 further comprising, determining the value of at least one property of said region, and performing the following acts after the generating, focusing and measuring:

changing the power of said first beam;

measuring a change in power of said reflected portion of said second beam in response to said changing;

computing, in a programmed computer, a ratio of the difference in power of said reflected portion of said second beam to a corresponding difference in power of said first beam; and

using said ratio and said value of said property to compute the thermal conductivity of a dielectric layer lying underneath said region by dividing said ratio by a predetermined constant.

20. The method of Claim 19 wherein: said region is included in a conductive line.

21. The method of Claim 19 wherein said constant is determined from the formula:

$$\sqrt{4\pi\varepsilon_0 \frac{c}{\lambda}}\left(\frac{q}{\pi k_B}\right)\left(\frac{1-R}{4}\right)\sqrt{\frac{3h_m h_i}{T_0}}\left(\frac{.92}{T_0}\right)\left(\frac{\rho_e(T_\theta)}{wh_m}\right)$$

where ε_0 is the dielectric constant of free space,

c is the speed of light,

λ is the wavelength of the probe beam,

q is the electron charge,

k_B is Boltzmann's constant,

R is the reflectivity of the region,

h_m is the thickness of the region,

h_i is the thickness of an insulator lying under the region,

T_0 is the ambient temperature,

w is the line width,

$\rho_e(T_\theta)$ is the resistivity at the Debye temperature.

22. An apparatus for evaluating a wafer, said apparatus comprising:

a first source of a first beam of photons having a first intensity modulated at a frequency sufficiently low to ensure transfer of a majority of heat from a region illuminated by said first beam by diffusion;

a second source of a second beam of photons having energy sufficiently lower than said energy of said first beam to avoid generation of more than a negligible amount of heat in said region when said second beam is incident on said region; and

a photosensitive element located in a path of a portion of said second beam, said portion being modulated at said frequency after reflection by said region, said photosensitive element generating a first signal indicative of an elevation in temperature of said region caused by incidence of said first beam.

23. The apparatus of Claim 22 further comprising:

a computer coupled to said photosensitive element and programmed to determine a ratio of the difference in power of said portion of said second beam reflected by said region to a corresponding difference in power of said first beam.

24. The apparatus of Claim 23 wherein the computer is further programmed to compute the resistance per unit length of said region by dividing said ratio by a predetermined constant.

25. The apparatus of Claim 24, wherein the constant is determined from the following formula:

$$\sqrt{4\pi\varepsilon_0 \frac{c}{\lambda}}\left(\frac{q}{\pi k_B}\right)\left(\frac{(1-R)}{4}\right)\sqrt{\frac{3h_m h_i}{K_i T_0}}\left(\frac{.92}{T_\theta}\right)$$

wherein:

c is speed of light in vacuum;

T is thickness of said region;

λ is wavelength of said first beam;

ε_0 is the dielectric constant of free space;

q is the electron charge;

k_B is the Boltzmann's constant;

R is absolute reflectance of said region;

h_m is the thickness of region;

h_i is the thickness of an insulating film lying underneath the region;

K_i is the thermal conductivity of the insulating film;

T_0 is the ambient temperature; and

T_θ is the Debye temperature.

26. The apparatus of Claim 23 wherein:

the computer is further programmed to use said ratio and a known value of said property to compute the thermal conductivity of a dielectric layer lying underneath said region by dividing said ratio by a predetermined constant.

27. The apparatus of Claim 26 wherein:

the predetermined constant is the slope of a line obtained by curve fitting a plurality of reflectance measurements on reference substrates.